EFFECT OF RACTOPAMINE HYDROCHLORIDE (PAYLEAN®) ON FRESH MEAT AND FURTHER PROCESSING CHARACTERISTICS OF MUSCLES FROM THE SHOULDERS OF FINISHING PIGS

BY

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THESIS

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Abstract

Ractopamine hydrochloride (RAC), a β-adrenergic agonist, increases muscle mass and decreases fat deposition in the pig. Though RAC has been extensively studied, to date no experiments have quantified its effect on the pork shoulder. Therefore, the objectives of this study were to characterize the effects of RAC on fresh meat and further processing characteristics of muscle from the shoulder of finishing pigs. Two hundred and forty shoulders originating from 120 carcasses (60 barrows and 60 gilts) were selected from a commercial population of pigs. This study was designed as a 2 x 2 factorial in a randomized complete design. Factors were RAC inclusion in the diet (0 mg/kg or 7.4 mg/kg) and sex (barrow or gilt). Paired shoulders (120 right sides and 120 left sides) were transported from a federally inspected harvest facility under refrigeration to the University of Illinois Meat Science Laboratory for evaluation. Subsequently, right and left shoulders were separated and designated for 2 separate experiments. Experiment 1 used the right shoulder to determine further processing characteristics. Cottage bacon was manufactured from cured and smoked CT Boston butts. Experiment 2 used the left shoulder to determine fresh meat characteristics. Due to the lack of interactions ($P > 0.05$) during both experiments, data were reported as main effect means. Pigs fed RAC had greater carcass weight ($P = 0.09$) and loin depth ($P = 0.03$) than controls. Inclusion of RAC increased shoulder cutability. Feeding RAC decreased Boston butt fat content ($P = 0.01$). In contrast, RAC inclusion had no effect on picnic fat content ($P = 0.86$). Inclusion of RAC also increased Boston butt salt soluble proteins (SSP) extractability ($P = 0.03$) at 0.5 % salt concentration. Surprisingly, RAC inclusion also improved ($P = 0.03$) picnic SSP extractability at 1.5% salt concentration. Feeding RAC had no effect on cottage bacon percent cooked yield ($P = 0.33$). However, RAC inclusion reduced ($P < 0.01$) cottage bacon fat content, and had no effect

on protein content (P = 0.50). In addition, RAC improved loin end (P = 0.07), middle end (P = 0.07), and blade end (P < 0.01) slice lean area. Cottage bacon from RAC-treated pigs had sensory characteristics similar to controls. Shoulders from pigs fed RAC might be of benefit to the industry because they provide more pounds of sellable products with decreased fat content and greater lean area in cured Boston butt. At the same time, no detrimental effects on processing characteristics and sensory attributes of cottage bacon were observed. These results are in agreement with most of the literature that RAC supplementation produces heavier and leaner carcasses with little to no impact on pork meat quality.

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Chapter I

Review of Literature

Introduction

The meat industry today is consumer driven, rather than production driven, unlike decades ago. Consumers demand lean products with the least possible amount of fat. In the same manner, packers and processors demand carcasses that provide the greatest yields with the least amount of trim and no hazards to human health. These circumstances have led to the use of β-adrenergic agonists (β-agonists) by the livestock industry in order to meet the expectations of today's market. In general, β-agonists increase muscles mass and decrease fat deposition in the carcass. This response has been consistent in the five major animal species destined for meat consumption. Sheep and cattle showed greater response than turkeys, pigs showed greater than broiler chickens (Mersmann, 1998; Moody et al., 2000). β-agonists are organic compounds with a structure very similar to that of the catecholamines naturally found in the animal, epinephrine and norepinephrine. Currently, only two compounds are approved by the Food and Drug Administration (FDA) to use in meat production animals; Zilpaterol (trade name Zilmax®, Intervet division of Schering-Plough Animal Health, Summit, NJ) for beef cattle and Ractopamine hydrochloride (RAC – Elanco Animal Health division of Eli Lili, Greenfield, IN) marketed under the following trade names: Optaflexx®, Paylean® and Topmax® for beef, pork and turkey production, respectively. Paylean® is currently labeled for use at a dose of 5 – 10 mg/kg for the last 20.5-40.9 kg of gain prior to slaughter in pigs initially weighing at least 68 kg.

The aim of this literature review will be focus on the effects of RAC on the pig carcass with special interest on the shoulder of finishing pigs.

Ractopamine Hydrochloride

Description and Mode of Action

Ractopamine, along with epinephrine and norepinephrine, belong to a group of organic compounds called phenethanolamines. These compounds bind to the alpha adrenergic receptors (α-ARs) and beta adrenergic receptors (β-ARs) located on the surface of the cell. Phenethanolamines are characterized by a substituted aromatic ring and an ethanolamine side chain with various substitutions on the aliphatic nitrogen (Ruffolo, 1991; Smith, 1998). In addition, coupling of phenethanolamines with β-AR results in activation of Gs proteins, which in turn will stimulate adenylyl cyclase resulting in a cascade of reactions that will eventually concluded with the phosphorylation of numerous enzymes and regulatory factors important in metabolic regulation (Moody et al., 2000). The latter may trigger a series of physiological responses that result in increased carcass leanness and decrease fat content (Mersmann, 1998). There are three subtypes of β-AR, namely β_1, β_2 and β_3, and their distribution varies between species and tissues, but β-ARs are present in almost all mammalian cells. The β_1 subtypes are the most abundant receptor subtype present in pig tissues, accounting for 80% in adipose, 72% in heart, 65% in lung, 60% in skeletal muscle and 50% in liver (McNeel and Mersmann, 1999; Liand et al., 2002).

In adipose tissue, activation of β-ARs results in increased protein kinase A activity leading to activation of hormone-sensitivity lipase with subsequent triglyceride hydrolysis. In addition, protein kinase A also inhibits lipogenesis due to phosphorylation and inactivation of glucose transport and acetyl Coa carboxylase and reduced expression of lipogenic genes (Mills and Mersmann, 1995; Mersmann, 1998). Pigs fed RAC have reduced carcass fat (Moody et al., 2000). Numerous experiments have reported that RAC remarkably increases plasma free fatty acids in vivo and in vitro (Veenhuizen et al., 1987; Liu et., 1994). However, this response might be of short duration because 50% of βARs are down-regulated after 7 days of oral administration (Spurlock et al., 1994).

The majority of evidence points out that β-AR are involved in the growth response. Initial reports suggested that β-AR antagonist did not inhibit skeletal muscle growth (Reeds et al., 1988). In contrast, subsequent reports indicated that β-AR mediate the growth response (Choo et al., 1992). However, it remains uncertain whether the effect of β-AR on skeletal muscle growth are direct or indirect. A direct link seems likely as in a study conducted by Byrem et al., (1998) infusion of the β-agonist cimaterol to the hind limb of cattle increased amino extraction across the limb, suggesting that direct effects were responsible for increased protein gain. Furthermore, β-agonists have little effect on the levels of circulating hormones known to influenced growth and metabolism (Moody et al., 2000). A temporary increase in blood flow to skeletal muscles have been reported, which would increase nutrient availability and probably contribute to the growth response (Byrem et al., 1998; Mersmann, 1998).

The major effect of β-agonist on muscle fiber is to cause hypertrophy without an increase in DNA, suggesting that protein synthesis and degradation, or both are affected (Mills, 2002). In a study conducted by Aalhaus et al. (1992) RAC-fed pigs had increased muscle fiber size in large part due to a change in fiber type as red fibers shifted to white fibers. In the same study, RAC also increased the size and percent of intermediate fibers. Adeola et al. (1992) reported that feeding RAC increased fractional protein synthesis and accretion accompanied with an increased in myofibrillar protein synthesis at expense of sarcoplasmic protein synthesis. Unlike other β-agonists, RAC has little effect on protein degradation. In an experiment conducted by Ji (1992) RAC-fed pigs had increased m calpain activity with no effect on either μ calpain or calpastatin activity. In the same manner, Bergen et al. (1989) reported increased activity of cathepsin L, but no effect on cathepsin B and H, and the calcium-dependent proteases following RAC feeding in pigs. These findings suggest that RAC increase muscle mass by increasing protein synthesis with little effect on protein degradation. In a review by Moody et al. (2000), it was concluded that due to differences in βAR subtype specificity of RAC (β1) compared with cimaterol (β2) protein degradation is not affected. Moreover, activation of β2 receptors stimulates protein synthesis and a reduction in protein degradation, whereas activation β1 only stimulate protein synthesis.

Effect on Carcass Traits

β-adrenergic receptor agonists are often referred as repartitioning agents due to their ability to redirect nutrients away from adipose tissue toward muscle (Ricks et al., 1984). Thus, increasing leanness and dressing percentage. Incorporation of RAC to the diet of finishing pigs for the last 20.4 to 40.8 kg of BW have resulted in increased carcass weight and dressing percentage with little effect on meat quality (Stites et al., 1991; Uttaro et al., 1993; Carr et al., 2005a; Carr et al., 2005b; Apple et al., 2007; Kutzler et al., 2011). In addition, beneficial effects on carcass cutting yields have been documented (Crome et al., 1996; Carr et al., 2005a; Fernández-Dueñas et al., 2008; Carr et al., 2009; Kutzler et al., 2011). Nonetheless, response to RAC is dependent on dosage, duration, and dietary protein. Lower dosages (≤ 10 mg/kg) results in mild increments in carcass characteristics whereas higher dosages (> 10 mg/kg) optimize these characteristics (Watkins et al., 1990; Stites et al., 1991; Armstrong et al., 2004). Similarly, feeding RAC might be limited to the final 3 to 4 weeks of the finishing period due to a plateau in weight gain. However, improvements in carcass composition may continue as duration is increased (Williams et al., 1994). The levels of dietary protein should be increased to at least 16.7% in order to compensate for the increase in lean deposition (Dunshea et al., 1993).

The effect of RAC on 10th rib fat depth has been inconsistent. In general, several authors have reported a reduction in fat depth ranging from 7% to 16% in RAC-fed pigs (Herr et al., 2001; Merchant-Forde et al., 2003; Apple et al., 2004a; Carr et al., 2005b). On the contrary, other authors have reported similar fat depth between RAC and controls pigs (Crome et al., 1996; Carr et al., 2005a; Leick et al., 2010; Kuztler et al., 2011). RAC dose might a possible explanation behind this discrepancy in response. Watkins et al. (1990) reported that in order to maximize the benefits of RAC on leanness, dose equal or greater than 10 mg/kg might be required.

Contrary to 10th rib fat depth, there is little doubt that RAC inclusion increases loin size. Numerous studies have reported increases in loin area ranging from 2.8 to7.4 cm^2 (Yen et al., 1991; Merchant-Forde et al., 2003; Armstrong et al., 2004; Carr et al., 2005a; Carr et al., 2005b) and increases in loin depth from 0.3 to 0.5 cm (Herr et al., 2001; Apple et al., 2004a; Brumm et al., 2004; Fernández-Dueñas et al., 2008; Boler et al., 2011; Kutzler et al., 2011).

Conflicting results have been reported when analyzing the effect of RAC on carcass lean content. In an experiment conducted by Armstrong et al., (2004) comparing RAC at different dose and durations it was reported that 27 days of oral administration of RAC increased carcass lean. On the other hand, several authors have indicated no difference between RAC-fed pigs and controls (Stites et al., 1991; Brumm et al., 2004; Rincker et al., 2009; Leick et al., 2010). A possible explanation behind this phenomenon might be that lean prediction equations contains biases, and therefore underestimate the magnitude of the effects of RAC supplementation (Schinckel et al., 2003). In order to accurately predict the impact of feeding RAC on carcass leanness more precise methods should be use, such as; dissection (separation of lean and fat tissue) and chemical analysis (Schinckel et al. 2003). The majority of the time, carcass dissection agreed with an increased in carcass percent lean in favor of RAC pigs (Watkins et al., 1990; Crome et al., 1996; Xiao et al., 1999; Schinckel et al., 2001).

Effect on Meat Quality

Meat quality, for the scope of this review, is defined as those attributes that directly impact the appearance (pH, color, and water holding capacity) and eating experience (texture, juiciness and flavor) of pork. In general, feeding RAC to pigs has little to no impact on meat quality (Uttaro et al., 1993; Carr et al., 2005a; Carr et al., 2005b; Fernández-Dueñas et al., 2008; Kutzler et al., 2011).

Ultimate pH is one the most easy and common measurement used in the meat industry to predict meat quality. Furthermore, in an experiment conducted by Boler et al. (2010), it was suggested that pH at 24 hours postmortem was the strongest predictor of pork meat color, water holding capacity and tenderness. The majority of studies have reported similar effects between RAC and control on ultimate pH measured in loins (Aalhaus et al., 1990; Stites et al., 1994; Stoller et al., 2003; Carr et al., 2005b; Fernández-Dueñas et al., 2008). However, a close observation of these studies reveals a numerical increased in pH in favor of RAC. In addition, Apple et al. (2004b), Rincker et al. (2009) and Kuztler et al. (2010) reported that RAC-fed pigs had higher loin ultimate pH than controls. In another study conducted by Boler et al. (2011) RAC inclusion also increased ultimate pH of 4 muscles in the ham. Mersmann et al. (1998)

suggests that β-agonists stimulate cyclic adenosine monophosphate (cAMP) thus glycolysis is activated causing a depletion of muscle glycogen prior to slaughter resulting in higher pH postmortem.

Water holding capacity refers to the ability of meat to bind or retained moisture during storage. Consistent with the effects on pH, RAC feeding had no detrimental effect on percent drip loss (Aalhaus et al., 1990; Stoller et al., 2003; Rincker et al., 2005). In a recent study conducted by Kutzler et al. (2010) loins from RAC fed pigs had less drip loss than controls after a 24 h storage period.

Fresh pork color is usually characterized objectively using colorimeters (CIE, 1978) and subjectively using a set of standards such as, those by the NPPC (1999) or Japanese color standards. The present review will focus on the effect of RAC supplementation of objective color. Most of the data available on meat quality was using the longissimus muscle as indicator of the whole pork carcass. RAC feeding has little to no effect on L* (lightness) values. On the contrary, a mild but, persistent reduction in a* (redness) and b*(yellowness) has been reported in RAC-fed pigs (Uttaro et al., 1993; Apple et al., 2004b; Rincker et al., 2005, Carr et al., 2005a.; Carr et al., 2005b; Fernández-Dueñas, et al., 2008; Kutzler et al., 2010). As previously described RAC caused an increase in the proportion of white fibers in muscle (Aalhaus et al., 1992). This shift in muscle fiber type suggests a decrease in myoglobin content; because white fibers have less myoglobin than red and intermediate fibers. The reported decreased in a* and b*, regardless of statistical significance, is of little practical implication as consumers may not detect difference between RAC and control pork meat.

One of the most important parameters when evaluating a feed ingredient in livestock, is whether or not it can cause adverse effect on the sensory attributes of the final product. Sensory evaluation from several studies have reported that loins from RAC-fed pigs had similar pork flavor intensity, juiciness and tenderness as loins from control-fed pigs (Stites et al., 1994; Carr et al., 2005a; Carr et al., 2005b; Rincker et al., 2005; Fernández-Dueñas et al., 2008; Rincker et al., 2009). Therefore, this indicates that RAC can be added to the diet of finishing pigs with no detrimental effect on palatability.

Effects on Further Processed Meat Products

The meat industry use further processing as a way to develop value added meat products. However, the quality of the end product is determined in large part by the chemical composition of the raw materials. Consequently, any discussion on further processing should begin with the concept of protein functionality. This refers to the ability of myofibrillar proteins to interact with fat, water and other proteins present in the meat. Myofibrillar proteins, mainly actin and myosin, influence the processing characteristics of meat products. Moreover, these proteins when solubilized by the addition of salt form an exudate that eventually, with the application of heat, will bind meat pieces together. Feeding RAC to finishing pigs, not only increased the rate of fractional protein accretion and synthesis, but also the synthesis of myofibrillar proteins (Adeola et al., 1992). Therefore one would expect that raw materials from RAC-fed pigs may have better protein functionality and processing yields than untreated pigs. In an experiment conducted by Uttaro et al. (1993) RAC hams were leaner and heavier, and had greater cooking yields than controls. In the same manner, Stites et al. (1991) reported heavier hams, but with similar cooked yield and fat content as controls. The observed discrepancy in cooked yield between studies may be attributed to pump level. Uttaro et al. (1993) pumped hams to a target of 125% of green weight, while the hams from the Stites et al. (1991) were pumped to 110% of green weight. In another study, Boler et al. (2011) reported no advantage in salt soluble protein extractability between RAC and control hams, but a numerical increased in cook yield in favor of RAC. Stites et al. (1994) reported no effect of RAC on the visual appearance and palatability characteristics of cured hams and loins.

There was a general concern that RAC feeding would make bellies thinner, therefore making bacon processing more difficult. Several studies have reported no detrimental effects on bacon quality characteristics and processing yields (Stites et al., 1990; Uttaro et al., 1993; Leick et al., 2010). Furthermore, Scramlin et al. (2008) reported that RAC increased belly yield and resulted in similar belly thickness compared to controls. In the same study, bacon slices were analyzed to determine visual composition. Bacon slices from RAC-fed pigs had greater total area and lean area, but same fat area as controls. On the other hand, loins from RAC-fed pigs had fat content and pumped uptake similar to controls (Leick et al., 2010). On the contrary, Carr et al. (2005a) observed a trend toward decreased in loin percent pump uptake in RAC loins.

In summary, the evidence presented suggests that RAC inclusion to the diet of finishing pigs, at the very least, had no detrimental effect on the processing characteristics and sensory attributes of further process meat products, such as ham, bacon and enhanced loins.

Effect on Pork Shoulder

Over the last 30 years, ractopamine has been extensively studied (see reviews by Moody et al., 2000; Apple et al., 2007). However, little is known about its effects on the pork shoulder. This may be attributed to a lower value of the shoulder in the US compared to the other primals (belly, ham and loin) of the pork carcass. The limited information available on RAC shoulders is centered primarily on cutting yields. In an early experiment conducted by Stites et al., (1991) RAC-fed pigs had similar whole shoulder weight as controls. However, RAC shoulders had heavier Boston butts than controls. Similarly, Crome et al., (1996) reported improved weight and yields in favor of RAC shoulders from pigs marketed at either 107 kg or 125 kg. In a more recent experiment Kutzler et al., (2011) reported that increasing RAC feeding for an extra 7 days (35 d total) resulted in increased boneless Boston butts and picnic weights; which in turn resulted in heavier cellar trimmed Boston butts. On the other hand, consistent with the sensory evaluation conducted on enhanced loins and cured hams; Jeremiah et al., (1994) reported that shoulder roast from RAC- treated pigs had similar sensory attributes as controls. A summary of the effects of RAC on shoulder cut-out values and sensory attributes are presented in Table 1. Overall, one may suggest that the common benefits associated with RAC feeding, increase muscle mass and decrease fat depot, were also observed in the shoulders. RAC shoulders were heavier and their individual parts were also heavier when expressed on a trimmed and boneless basis.

Pork Shoulder

Muscle Profile

Typically a pork carcass is comprised of 4 primals: Shoulder, loin, belly and ham. The pork shoulder is further composed of two sub-primals, Boston butt and picnic. In addition, numerous muscles comprise the pig shoulder. These muscles were segregated by Jones et al. (2006) into the following three groups: 1) Thorax, formed by Serratus ventralis and Pectoralis profundi; 2) Thoracic composed of the Triceps brachii, Teres major, Supraspinatus, Subcapularis and Infraspinatus; and 3) Dorsal composed Rhomboideus and Longissimus dorsi. Individual muscle characteristics are presented in Table 2. Shoulder muscles have a relatively high postmortem pH (5.97 – 6.31) when compared to loin (5.69), which is typically the reference muscle to measure carcass pH. The reported L* and a* values indicate that these muscles tend to be darker and redder in color when compared to a loin. Moreover, the reason behind these observed characteristics may be attributed to muscle fiber types.

Muscles differ on the basis of fiber composition and rate of muscle growth. Most muscles have a fiber composition which is a mix between light and dark fibers. In addition, dark muscles contain predominately type I (red-oxidative) and type IIa (red-glycolytic) muscle fibers. While light muscles contain predominately type IIb (white-glycolytic) muscle fibers (Klont, 1998). Also, higher ultimate pH values have been associated with the total oxidative capacity and area of type I fibers (Maltin et al., 1997). Specific to the shoulder, in an experiment conducted by Beecher et al. (1965) reported that the Serratus ventralis had greater than 40% concentration of type I muscle fibers. In a more recent experiment Karlsson et al. (1999) found that the Infraspinatus, Supraspinatus and Triceps brachii were all characterized as having type I muscle fibers. Muscle fiber type composition may influence pork quality measurements (Klont et al., 1998). Therefore, measurements such as individual muscle pH, objective color, water holding capacity and chemical composition may have a profound impact on the processing behavior and ultimately consumer acceptability of meat. In addition, higher proportion of type II muscle fibers seems to be associated with an improvement in meat quality (Aalhaus et al., 2010).

Further Processed Products from the Shoulder

From the Boston butt and picnic, a variety of further process items can be manufactured, thus adding extra value to the carcass. Prior to processing, the Boston butt is removed from bones and fat overlaying the blade. The resulting item according to standards described by the

Institutional Meat Purchase Specifications (IMPS, 1997) is referred as cellar trimmed butt (IMPS #407). This item is stuffed into casings, cured, smoked and cooked. This product is generally sold as cured and smoked pork shoulder butt (IMPS #530). This item may be sliced and fried as bacon. Based on the latter, some consumers in the northeast refer to this product as “cottage rolls” or “cottage bacon” (Kramlich et al., 1980). In addition, traditional Italian meat products may be manufactured using cellar trimmed butts (CT butts) as raw material. Among these Italian items, the most popular in the US are cooked capicolla and dried coppa. The first may be dry cured, immersion cured or pump cured. Subsequently, the cured product is coated with spices and paprika before cooking (Cross, 2006). In addition to dry curing, coppa processing involves drying and maturing of CT butts for an extended period of time, generally 3 – 12 months (Zanardi et al., 2000). In contrast to capicolla, coppa is usually sold uncooked, due to reduced available water (A_w) accomplished during drying and maturing.

Picnics may be cured, smoked and cooked (IMPS #526) similarly to CT butts. However, due to a greater proportion of bone, fat, connective tissue and lack of large muscles, cured picnics might be sold at a lower price than hams and butts (Kramlich, et al. 1980). Boneless picnics and Boston butt are characterized by low moisture to protein ratio (aprox. 3.50:1), which is favorable to manufacture of comminuted meat products such as, sausages, canned hams and bologna (Aberle et al., 2001).

The USDA specifies the amount of water in that should be added in further process products from the Boston and picnic (IMPS, 1996). The specification is based on the concentration of protein fat free (PFF) in the finished product. The PFF concentration reflects the presence of added ingredients, including water, and relates labeling claims to the percent of meat protein in the products. Therefore, both CT butts and picnic when cured, cooked and smoked should have a least 20% PFF in order to comply with USDA labeling regulations. In the same manner, 18%, and 16.5% and below 16.5% PFF will result in products with "natural juices", "water added", and "water product" labeling statements.

Objectives

To the date there is little information on the literature in regards to fresh meat and processing characteristic of the shoulder; therefore the objectives of these research were:

1. Characterize muscles from the shoulder and to evaluate the impact on the processing characteristics of the Boston butt of finishing pigs fed a RAC program diet at 7.4 mg/kg for the last 28 days prior to harvest.
2. Demonstrate that feeding RAC have no detrimental effect on the processing characteristics of the Boston butt.

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Tables

Table 1. Review of Ractopamine effects on shoulder cut-out values and sensory attributes

Effect	**Reference**
Increase whole shoulder wt	Crome et al., 1996
	Carr et al., 2005a
	Kutzler et al., 2011
No effect on whole shoulder wt, % of HCW	Crome et al., 1996
	Carr et al., 2005a
	Kutzler et al., 2010
	Kutzler et al., 2011
Increase boneless shoulder wt	Fernández-Dueñas et al., 2008
Increase trimmed Boston butt wt	Stites et al., 1991
	Crome et al., 1996
	Carr et al., 2005a
	Carr et al., 2008
	Kutzler et al., 2010
	Kutzler et al., 2011
Increased trimmed Boston butt wt, % of HCW	Crome et al., 1996
	Carr et al., 2005a
	Kutzler et al., 2011
Increase boneless Boston wt	Crome et al., 1996
	Carr et al., 2005a
	Carr et al., 2008
	Kutzler et al., 2010
	Kutzler et al., 2011
Increase trimmed picnic wt,	Crome et al., 1996
	Carr et al., 2005a
	Kutzler et al., 2011
Increase boneless picnic wt	Crome et al., 1996
	Carr et al., 2005a
	Carr et al., 2008
	Kutzler et al., 2010
	Kutzler et al., 2011
Increase CT butt wt	Kutzler et al., 2011
No effects on shoulder roast sensory attributes (aroma, taste, mouthfeel and off-flavors)	Jeremiah et al., 1994

Table 2. Chemical and physical characteristic of the principle muscles in the pork shoulder[1] (N=30).

Muscle	**Group**	**Common name**	**pH**	**WHC (%)**	**L***	**a***	**b***	**Heme Iron (μg/g)**
Serratus ventralis	Thorax	Cellar meat	6.12	5.74	42.73	20.93	5.59	9.38
Pectoralis profundi	Thorax	Deep pectoral	5.97	5.83	47.52	19.86	5.47	6.94
Triceps brachii	Thoracic	Picnic cushion	6.01	4.52	42.09	20.83	5.49	8.79
Teres major	Thoracic	-	-	-	-	-	-	-
Supraspinatus	Thoracic	Mock tender	6.09	5.13	45.02	20.27	5.14	9.77
Subcapularis	Thoracic	-	6.31	4.02	42.49	21.55	5.32	9.55
Infraspinatus	Thoracic	Flat iron	6.24	3.80	42.51	21.69	5.54	10.07
Rhomboideus	Dorsal	Hump	-	-	-	-	-	-
Longissimus dorsi	Dorsal	Loin	5.69	7.71	52.96	17.52	5.33	5.26

[1]Adapted from Jones et al., 2006.

Chapter II

Effect of Ractopamine Hydrochloride (Paylean®) on Fresh Meat and Further Processing Characteristics of Muscles from the Shoulders of Finishing Pigs

Abstract

The objectives of this study were to characterize the effects of ractopamine hydrochloride (RAC) on fresh meat and further processing characteristics of muscles from the shoulders of finishing pigs. Two hundred and forty shoulders originating from 120 carcasses (60 barrows and 60 gilts) were selected from a commercial population of pigs the study. This study was conducted as a 2 x 2 factorial in a randomized complete design. Factors were RAC inclusion in the diet (0 mg/kg or 7.4 mg/kg) and sex (barrow or gilt). Paired shoulders (120 right sides and 120 left sides) were transported from a federally inspected harvest facility under refrigeration to the University of Illinois Meat Science Laboratory for evaluation. Subsequently, right and left shoulders were separated and designated for 2 separate experiments. Experiment 1 used right shoulders to determine further processing characteristics. Cottage bacon was manufactured from cured and smoked CT Boston butts. Experiment 2 used left shoulders to determine fresh meat characteristics. Due to the lack of interactions ($P > 0.05$) during both experiments, data were reported as main effect means. Pigs fed RAC had greater carcass weight ($P = 0.09$) and loin depth ($P = 0.03$) than controls and RAC inclusion increased shoulder cutability. Feeding RAC decreased Boston butt fat content ($P = 0.01$), but no effect on picnic fat content ($P = 0.86$). Inclusion of RAC also increased the extraction of salt soluble proteins (SSP) from Boston butt ($P = 0.03$) at 0.5 % salt concentration. Surprisingly, RAC inclusion also improved ($P = 0.03$) picnic SSP extractability 1.5% salt concentration. Inclusion of RAC had no effect on cottage bacon

cooked yield ($P = 0.33$), reduced ($P < 0.01$) cottage bacon fat content, but had no effect on protein ($P = 0.50$). In addition, RAC improved loin end ($P = 0.07$), middle end ($P = 0.07$), and blade end ($P < 0.01$) cottage bacon slice lean area. Cottage bacon from RAC pigs had sensory characteristics similar to controls. Shoulders from pigs fed RAC might be of benefit to the industry because they provide more pounds of sellable products with decreased percent fat and greater lean area in cured Boston butt. At the same time no detrimental effects on the processing characteristics and sensory attributes of cottage bacon were detected with RAC inclusion.

Introduction

World population is projected to be approximately 9.25 billion people by the year 2050. That is a 35% increase over the actual population of 6.85 billion (US census Bureau, 2011). In addition, land areas destined for food production will remain virtually unchanged for the next three decades (FAO, 2002). This scenario has pushed the scientific community to search for new technologies to maximize food production with the least amount of inputs. One technology available for production of meat animals are β-adrenergic agonists (β-agonists). In general, β-agonists improve efficiency of meat animal production systems by increasing rate of weight gain, feed utilization efficacy, leanness and dressing percentage (Moody et al., 2000). These organic compounds are also known as repartitioning agents, as they redirect nutrients from fat accretion towards protein deposition, therefore increasing muscle mass (Ricks et. al, 1984). Repartitioning agents' efficacy have been documented across the four major species destined for meat production. Cattle and sheep showed larger responses than swine, with the smallest response in broilers (Mersmann, 1998).

Ractopamine hydrochloride (RAC; Paylean®, Elanco Animal Health, a division of Eli Lilly and Co., Greenfield, IN) is currently the only β-agonist approved by the FDA for use in swine diets. Paylean® is currently labeled for use at a dose of 5 – 10 mg/kg for the last 20.5-40.9 kg of gain prior to slaughter in pigs initially weighing at least 68 kg.

In a meta-analysis conducted by Apple et al. (2007) indicated that feeding RAC, regardless of the dose, improved live animal performance, increased carcass weights and leanness with no detrimental effects to meat quality. In addition, the benefits in carcass characteristics were more persistent at higher doses (10 mg/kg and 20 mg/kg). Furthermore, RAC has been studied in the ham (Boler et al., 2011b; Fernández-Dueñas et al., 2008), belly (Scramlin et al., 2008), and loin (Stites et al., 1991; Apple et al, 2004; Carr et al., 2005ab; Rincker et al., 2005; Rincker et al., 2009;) and in a wide variety of doses and durations (Armstrong et al., 2004; Kutzler et al., 2011), but to date no studies have evaluated fresh and further processed product characteristics of the shoulder. The objectives of this study were to characterize muscles from the shoulder and to evaluate the impact on the processing characteristics of the Boston butt of finishing pigs fed a RAC program diet at 7.4 mg/kg for the last 28 days prior to harvest.

Materials and Methods

Experimental procedures during the live phase of the study followed the guideline stated in the Guide for the Care and Use of Agriculture Animals in Agricultural Research and Teaching (FASS, 2010). Pig shoulders were obtained from a federally inspected commercial harvest facility.

Shoulder Selection

Two hundred and forty shoulders originating from 120 carcasses (60 barrows and 60 gilts) were selected from a commercial population of pigs that were fed a diet containing, either 0 mg/kg or 7.4 mg/kg RAC (ractopamine hydrochloride – Elanco Animal Health, a division of Eli Lily Co., Greenville, IN) for the last 28 days of feeding prior to slaughter. The study was conducted as a 2 x 2 factorial in a randomized complete design. Factors were RAC inclusion in the diet (0 mg/kg or 7.4 mg/kg) and sex (barrow or gilt). Thirty carcasses closest to the mean hot carcass weight (HCW) of each RAC by sex combination were chosen. Pigs were identified by lot number to a treatment (diet by sex), but individual carcass identification was not retained. During harvest, loin depth (10^{th} rib), fat depth (10^{th} rib) and calculated percent lean measurements were collected (Fat-O-Meater measurements, SFK Tecnology Fat-O-Meater, Herley, Denmark). Carcasses were sequenced to allow for identification of individual carcass data with lot number. Following harvest, carcasses were chilled for 24 hours at 2 ^{o}C. The next morning, paired shoulders (120 right sides and 120 left sides) from each carcass were collected from the fabrication line and placed in combos. Shoulders were transported under refrigeration to the University of Illinois Meat Science Laboratory for further processing and evaluation.

Shoulder Fabrication and Quality Characteristics

Shoulders were fabricated according to standards described by Institutional Meat Purchase Specifications (IMPS, 1997). Initially, the whole shoulder, with neck bones and jowl on, was weighed, trimmed (IMPS #403) and weighed again. Trimmed shoulders were further fabricated into a bone-in picnic shoulder (IMPS #405), boneless picnic shoulder (IMPS #405A), shoulder cushion (IMPS #405B, triceps brachii), bone-in Boston butt (IMPS #406), boneless

Boston butt (IMPS #406A) and cellar trimmed (CT) boneless Boston butt (IMPS #407). The summation of paired shoulders and its parts were used to calculate cutting yields as a percent of HCW. Weights of individual shoulder parts were averaged for the two paired shoulders from each carcass. After fabrication, an ultimate pH value was collected at 48 hours postmortem with a pH star probe (SFK Technologies, Peosta, IA) in the Triceps brachii and Seratus ventralis from both paired shoulders. Objective color (CIE, 1978) scores were measured on the same muscles with a Minolta CR-400 using a D65 light source, a ^{o}0 observer, and calibrated against a white tile (Minolta Camera Company, Osaka, Japan). Objective color scores and ultimate pH values were averaged across paired shoulders and the mean of the two values were reported. Next, right and left shoulders were separated and designated for 2 separate experiments. Experiment 1 used the right shoulder to determine further processing characteristics. Cottage bacon was manufactured from cured and smoked CT Boston butts. Experiment 2 used the left shoulder to determine fresh meat characteristics. Individual identification of picnics and Boston butts from both sides was maintained throughout the experiments.

Experiment 1, Shoulder Further Processing

Cottage Bacon Manufacturing and Analyses

A total of 60 CT butts (15 from each sex and RAC combination) were randomly selected to determine further processing characteristics. Shortly after fabrication, CT butts were placed in combos and kept under refrigeration (2 ^{o}C) for 24 hours (72 hours postmortem). Each CT butt was weighed in order to determine green weight and then injected with a multi-needle injector using a Schroder Injector/Marinator, Model N50 (Wolf-Tec, Inc, Kingston, NY) with a commercial cure solution to target 110% of the original green weight. Prior to injection, CT butts were separated into controls and RAC to target a similar pump uptake and the injector was adjusted for dwell time and pressure between control and RAC samples. A commercial cure solution was formulated to deliver: 1.52% salt, 0.33% sodium tripoly / hexametaphosphate blend, 0.014% sodium nitrite, and 0.05% sodium erythorbate in the finished product. Immediately after injection, CT butts were weighed again to determine pumped weight and percentage of cure uptake. The following equation was used to calculate percent cure uptake: $\left(\frac{Pumped\ Weight - Green\ Weight}{Green\ Weight}\right) x100$. After weighing, CT butts were allowed to equilibrate for 72 hours to allow for complete distribution of the cure solution. Then CT butts were netted and weighed again to determine netted weight. Once netted and weighed, CT butts were cooked in an Alkar smokehouse (Lodi, Wisconsin) for 10 hours to 65.5^{0}C internal temperature. After cooking, cottage bacons were showered with cold water, immediately removed from the netting, weighed to determine hot cooked weight, chilled at 4 °C for 24 hours and weighed again to determine final cooked weight. The following equation was used to determine evaporative loss: $\left(\frac{Hot\ cooked\ Weight - Final\ cooked\ weight}{Final\ cooked}\right) x100$ and cook yield was calculated with the equation: $\left(\frac{Final\ cooked\ Weight}{Green\ Weight}\right) x\ 100$. Next, cottage bacons were individually vacuum packaged and stored under refrigeration (2 °C) for further analysis. After a 30 day storage period, cottage bacons were sliced using a deli slicer. The deli slicer was set up to cut 3.5 mm slices. In addition, each cottage bacon was oriented in the slicer so that, the posterior end (loin side) was sliced first. Immediately after slicing, cottage bacon orientation was maintained and samples were collected to determine visual percent lean, sensory evaluation, proximate composition and instrumental cured color.

Three slices were identified based on anatomical location as loin end (25% of the length of the CT Boston butt from the posterior end), middle (50%), and blade end (75%). Subsequently, each slice was photographed and analyzed for percent lean using image analysis software with the methodology described by Scramlin et al., (2008) and Boler et al., (2011a). A slice from the center (50% of the length of the CT butt from posterior) of the cottage bacon was used to determine cured color. Objective CIE L*, a*, b* color scores were collected using a Minolta CR-400 utilizing a D65 light source, 0^{o} observer, calibrated against a white tile. Four objective color measurements were taken randomly in the surface of the slice. Reported values are the average of the four measurements. Two slices from the center were also collected to determine proximate composition. Moisture percentage was determined as described by method 950.46 of the AOAC (1995) and extractable lipid percentage determined as described by Novakofski et al., (1989). Another six slices were removed from the center to determine sensory characteristics of cottage bacon by a six member trained panel and evaluated sensory attributes independent of each other for texture, juiciness, saltiness and off-flavors. These attributes were recorded on a 15-cm anchored unstructured line scale, where 0 = mealy, extremely dry, no salty and no off flavor, and 15 = rubbery, extremely juicy, extremely salty and intense off flavor. Slices were heated before they were served to a panelist in a South Bend convection oven (model V & Vs-15 single supply P/N 116-2012) at 121 ^{o}C for 10 minutes and covered with aluminum foil to prevent cooling. Each panelist was given a 3.5 mm thick slice and was instructed to cut a strip from the center and evaluate the piece.

Experiment 2, Shoulder Fresh Meat Characteristics

One hundred and twenty left shoulders were used to determine fresh meat characteristics. Initially, boneless Boston butts and picnics were homogenized for 4 revolutions in a commercial bowl chopper. Next, three samples of the homogenate were collected and frozen (-20 °C) for later determination of proximate composition, water holding capacity and salt soluble protein (SSP) content. Samples collected for proximate composition and SSP were further homogenized in a food processor before analysis. Proximate composition was determined in the same manner as described for experiment 1. Determination of SSP content was accomplished using the methodology described by Boler et al., (2011b). And were reported as percent of wet tissue weight and as a percent of total protein. Determination of water holding capacity (WHC) was accomplished by a modification of the centrifuge method described by McCaw et al., (1997). A 3 g sample was placed on a 7.5 cm x 7.5 cm square nylon mesh (45 μm opening, 30% of area open) and suspended in a 15 ml centrifuge tube. The sample was kept in place by overlapping the mesh outside of the tube with the cap. The tubes were centrifuge at 2,000 x g for 5 min. After centrifugation, meat and mesh were weighed again and the percentage loss was calculated. In order to increase accuracy of the measurement, the assay was performed in duplicate.

Statistical Analysis

The statistical analyses for both experiments were conducted in a similar manner. The experimental unit for the whole study was the individual carcass. A total of 120 carcasses (240 paired shoulders) were evaluated for this study. Data were analyzed as a randomized complete design in a 2x2 factorial arrangement. Therefore, the statistical model included the main effects of RAC inclusion and sex and their first order interaction. Differences in fat-o-meater measurements, cutting yields, chemical composition, pH, water holding capacity, objective color, visual percent lean, processing yield and sensory characteristics between the treatments were determined using the Mixed procedure of SAS (SAS Institute, 2004). Differences in salt soluble proteins were analyzed as repeated measures over increasing salt concentrations. Due to the lack of interactions (P > 0.05) during both experiments data were reported as main effect means. Assumptions of ANOVA were tested with Levene's test and Brown and Forsythe for homogeneity of variances. Normality of residuals was tested using the Univariate procedure of SAS.

Results and Discussion

Carcass Population Characteristics, Shoulder Cutability and Meat Quality

Carcass characteristics from the population of pigs used in the study are reported in Table 3. Pigs fed RAC had greater loin depth (P = 0.03) than controls. Inclusion of RAC increased HCW (P = 0.09) 1.44 kg over controls. In addition, RAC-fed pigs were 1.25% points leaner, as RAC inclusion increased carcass estimated percent lean (P = 0.18). The increasing effect of RAC on HCW (Stites et al., 1991; Herr et al., 2001; See et al., 2005), estimated percent lean (Fernández-Dueñas et al., 2008; Rincker et al., 2009) and loin depth (Apple et al., 2004; Brumm et al., 2004; See et al., 2005; Boler et al., 2011b) has been well established over the years. Results in this study are in agreement with all previous experiments. On the other hand, an interaction between RAC inclusion and sex was observed on back fat depth (P < 0. 01). While RAC reduced fat depth from 24.97 mm to 22.33 mm in barrows, no response was observed in gilts. A survey of the literature suggests that the effect of RAC on 10th rib fat deph has been inconsistent; while many studies (Uttaro et al., 1993; Merchant-Forde et al., 2003; Apple et., 2004; Carr et al., 2005b) report a reduction in fat depth others (Stoller et al., 2003; Brumm et al., 2004; Carr et al., 2005a; See et al., 2005) disagree.

The effects of RAC inclusion and sex on shoulder cut-out values are presented in Table 4. Supplementation with RAC resulted in carcasses with greater whole shoulder weights (P = 0.05) and trimmed shoulder weights ($P < 0.01$) than controls. In the same manner, RAC supplementation increased weight of individual shoulder parts along with greater cutting yields as percent of HCW. These effects were more evident in the Boston butt than in the picnic, as RAC increased Boston bone-in weight ($P < 0.01$), boneless Boston weight ($P < 0.01$), CT butt weight ($P < 0.01$) and their cutting yields. Smaller improvements by RAC were observed in bone-in picnic weight ($P = 0.09$) and boneless picnic weight ($P = 0.06$). These results are in agreement with previous experiments (Uttaro et al. 1993; Crome et al. 1996; Carr et al. 2005a) where RAC inclusion increased individual shoulder weight, parts and yields. An interaction ($P = 0.04$) was found for shoulder cushion weight. Barrows fed RAC had greater shoulder cushion weight (0.80 kg) than controls (0.72 kg). Nonetheless, RAC gilts (0.76 kg) and controls (0.77 kg) had similar shoulder cushion weight. The current results agreed with Stites et al. (1991), who reported no effect of RAC on trimmed picnic weight, however that study used carcasses under 85 kg.

Inclusion of RAC and sex had no effect on instrumental color of Serratus ventralis and Triceps brachii (Table 5). An interaction between RAC inclusion and sex was observed on Serratus ventralis ($P = 0.05$) and Triceps brachii ($P = 0.01$) pH values (Table 6). Ractopamine tended to increase Serratus ventralis pH ($P = 0.18$) 0.08 units in barrows. The opposite was observed in gilts, where RAC-fed gilts tended to have a decreased in pH ($P = 0.14$) of 0.08 units. A similar response to RAC was observed in Triceps brachii. In general, RAC barrows had the highest Triceps brachii pH (6.25); whereas RAC gilts had the lowest Triceps brachii pH (6.06). The reason behind these observed differences in pH response to RAC between barrows and gilts is unclear. In a recent study, Kutzler et al. (2011) found no difference in loin and ham pH when RAC was fed to pigs at 5 and 7.4 mg/kg. On the other hand, Boler et al. (2011b) showed that

RAC increased pH in four muscles from the ham. Contrary to our study, but in the Adductor muscle Boler et al. (2011b) reported that RAC increased gilt pH and had no effect on the barrow.

Fresh Meat Characteristics

The effects of RAC and sex on proximate composition are reported on Table 7. Feeding RAC decreased Boston butt fat content ($P = 0.01$) to 15.47% from 16.96%. In contrast, RAC inclusion had no effect on picnic fat content ($P = 0.86$). Gilts had greater Boston butt moisture content ($P = 0.03$) and less fat content ($P < 0.01$) than barrows. An interaction ($P = 0.02$) between RAC and sex was observed on Boston butt protein content. Barrows fed RAC had greater percent protein (18.72%) than controls (18.09%). However, RAC-fed gilts had similar protein content (18.74%) as controls (18.98%). On the contrary, gilts ($P < 0.01$) and RAC-fed pigs ($P = 0.01$) had greater picnic protein content than barrows and controls. In general, β-agonists redirects nutrient from adipose tissue and toward muscle growth (Ricks et al. 1984). For instance, in a study conducted by Yen et al. (1991) RAC inclusion reduced ham fat content in lean and obese genotypes. Similarly, Dunshea et al. (1993b) and Mitchell et al., (1991) reported that RAC-fed pigs had less empty body weight and whole carcass fat content respectively. The mode of action of β-agonists in skeletal muscle might indicate that muscle mass is increased by a combination of inhibiting protein turnover and enhancing protein synthesis (Mersmann, 1998). Unlike other β-agonists, RAC mainly affects protein synthesis (Bergen et al., 1989). Increased protein and moisture content in different tissues have been reported due to RAC feeding (Xiao et al., 1993; Dunshea et al., 1993a; Uttaro et al., 1993; Boler et al., 2011b). The present study further validates these effects. An interaction ($P = 0.02$) between RAC and sex was also observed on picnic moisture content. Barrows fed RAC had greater moisture content (66.52 %) than controls (64.22 %). Whereas, RAC fed gilts had similar (P = 0.95) moisture content (67.36 %) as controls (67.40 %).

Supplementation with RAC (P = 0.69) and sex (P=0.09) had no effect on Boston butt water holding capacity (Table 7). These result are in agreement with Uttaro et al. (1993), who also measured water holding capacity in cured and cooked RAC hams using a centrifuge and reported no difference between the treatments. On the contrary, gilts had greater moisture loss (P = 0.04) than barrows.

The moisture-protein ratio (MPR) is an important indicator to characterize raw materials. This ratio provides guideline in predicting composition of finished products (Kramlich et al., 1980). In the present study, RAC inclusion and sex had no effect on Boston butt and picnic MPR (Table 7). This finding suggests that RAC inclusion had no detrimental effect on the shoulder MPR, therefore does not impose any limitation on its use as a raw material for the manufacture of further processed meat products.

Salt soluble proteins (SSP), both sarcoplasmic and myofibrillar, comprise approximately 85% of total muscle protein content. Myofibrillar proteins, mainly actin and myosin, account for roughly 60% of SSP and are solubilized at moderate concentrated salt solutions (> 0.3 M NaCl). Meanwhile, sarcoplasmic proteins constitute the remaining 25% and contrary to their counterpart become solubilized at weaker salt concentrations. Processing characteristics of meat products are largely determined by SSP extractability. Furthermore, actin and myosin function as binding agents to keep water and fat together in the finished product (Strasburg et al., 2008). The effects of RAC inclusion and sex on extractability of SSP of the Boston butt and picnic are illustrated in Figure 1 and 2. Gilts had greater SSPs extractability as percent of Boston butt tissue weight across salt concentrations (Figure 1A). The previous was expected as gilts were leaner than barrows. On the contrary, gilts and barrows had similar extractability when expressed as a percent of total protein (Figure 1C). Meanwhile, RAC inclusion increased Boston butt SSP extractability as percent of tissue weight ($P < 0.05$) at 0.5% salt concentration (Figure 1B). Inclusion of RAC also increased Boston butt SSP extractability as a percent of total protein ($P = 0.03$) at 0.5 % salt concentration (Figure 1D). Sex had no effect on picnic SSP extractability either as a percent of tissue weight (2A) or percent of total protein (2C) across salt concentrations. Inclusion of RAC improved picnic SSP extractability as a percent of tissue weight at 1.5% ($P < 0.01$), 2.5% ($P = 0.10$) and 3.5% ($P = 0.07$) salt concentration (Figure 2B). Surprisingly, RAC inclusion also improved ($P = 0.03$) picnic SSP extractability as a percent of total protein at 1.5% salt concentration (Figure 2D). This phenomenon may be attributed not only to an increase in total protein content but also an increase in synthesis of myofibrillar proteins. Furthermore, Adeola et al. (1992) reported that RAC treated pigs had greater synthesis of myofibrillar proteins than non-treated. Boler et al. (2011b) reported that RAC-fed pigs had less SSP extractability at 0.05% salt than controls when expressed as percent ham tissue weight and total protein. In the same study, gilts had increased SSP compared with barrows at 2.5% and 3.5% when expressed as percent of ham tissue weight and total protein. Results in the present study suggest that RAC picnics might be beneficial to the meat industry, due to increased protein solubility at 1.5% salt concentration. This would also suggest better protein functionality and ultimately better processing yields and finished products.

Further Processing Characteristics

Pigs fed RAC had better cottage bacon processing characteristics than controls (Table 9). Cottage bacon originating from RAC-fed pigs had greater green weight ($P = 0.02$), pump weight (P = 0.02), equilibrium weight (P = 0.03), netted weight (P = 0.02), hot cooked weight (P = 0.02) and reduced percent evaporative chill loss (P = 0.06) than controls. RAC had no effect on percent cooked yield (P = 0.33). However, RAC cottage bacons had an absolute percent increase in cooked yield of 0.89% over controls. Results in this study are in agreement with previous studies where RAC inclusion was beneficial or non-detrimental to the processing characteristics of further process products. Uttaro et al., (1993) reported improvement in processing yields of RAC hams over controls and suggested that the difference in processing yields might be due to increase lean and decreased fat of pigs treated with RAC. In another study, Leick et al. (2010) found no difference in bacon cooking yields between RAC and controls. In the present study, inclusion of RAC had no effect on percent cure uptake (P = 0.48). This was expected as RAC and controls CT butts were separated prior to injection to obtain similar percent cure uptake. As a result differences in CT butt weight due to RAC inclusion were maintained. Therefore, processing characteristics would not be confounded with cure uptake.

Proximate composition of cottage bacon was positively affected by RAC inclusion (Table 9). Inclusion of RAC reduced (P < 0.01) cottage bacon fat content to 16.90% from 18.83% and increased (P < 0.01) moisture content to 61.84% from 60.10%. Cottage bacon from RAC-fed pigs had protein content (P = 0.50) similar to controls. On the contrary, gilts had cottage bacon with 0.82% greater protein content (P = 0.02) and 2.35 less fat (P < 0.01) than barrows. Results from the present study somewhat agreed with Boler et al. (2011b), who reported that RAC hams had less fat content and greater protein than controls. In contrast, numerous experiments have found no difference in loin fat content and moisture due to RAC inclusion up to 10 mg/kg (Carr et al., 2005ab; Leick et al., 2010).

USDA specifications (IMPS, 1996) for added water in cured and cooked pork shoulder products is based on percent protein fat free (PFF) in the finished product. This standard reflects the presence of added ingredients, including water, and relates to labeling claims on the percent of meat protein in the product. In the present study, RAC inclusion (P= 0.48) and sex (P = 0.26) had no effect on percent PFF of cottage bacon (Table 9). Cottage bacon percent PFF ranged from 23.35 – 23.68, meaning that the product exceeded the labeling requirements for a minimum percent PPF (20%) of “cured and cooked CT butt”.

Ractopamine inclusion had no effect on cottage bacon L* (P = 0.69) and b* (P = 0.07) values. An interaction (P = 0.05) was observed between RAC inclusion and sex on a* (redness) values. Overall, RAC barrows had the lowest a* values (17.39); whereas RAC gilts the highest (18.92).

Ractopamine inclusion in the diet of finishing pigs improved cottage bacon slice visual lean percentage (Table 8). Pigs treated with RAC had greater average slice total area (P = 0.01), lean area (P < 0.01) and decreased seam fat percentage of total slice (P = 0.01) than controls. In addition, RAC improved loin end (P = 0.07), middle end (P = 0.07), and blade end (P < 0.01) slice lean area 4.04 cm^2, 3.98 cm^2 and 5.74 cm^2 respectively. Inclusion of RAC also increased blade end slice total area 7.2 cm^2 (P = 0.05) and decreased (P = 0.04) percent seam of total slice to 20.05% from 23.45%. These results are in accordance with proximate composition and processing characteristics presented previously as RAC cottage bacons had less fat and greater cooked weight than controls. On the other hand, barrows had greater average slice seam fat area (P = 0.06) and seam fat percentage of total slice (P = 0.02) than gilts. The previous response in barrows was also observed in middle end and blade end slices. Results from the present study are in agreement with Scramlin et al. (2008), who analyzed the visual composition of RAC bellies and reported that RAC bacon had greater total slice area, secondary lean area and percent lean area than controls.

Numerous experiments have reported that RAC inclusion had no effect on the sensory attributes of cured and uncured pork cuts (Jeremiah et al., 1994; Stites et al., 1994; Carr et al., 2005a; Rincker et al, 2005). The present study agreed with all those experiments. The panelists in the current study found similar sensory attributes between RAC cottage bacon and controls (Table 10). Surprisingly, gilts had greater off flavor intensity ($P = 0.04$) than barrows. Nonetheless, this result has little practical implication as the value detected was low.

Implications

Feeding RAC during the last 28 days before harvest at 7.4 mg/kg increased individual shoulder weight, parts and cutting yields as percent of HCW. Inclusion of RAC increased Serratus ventralis and Triceps brachii pH in barrows and had no effect on gilts. Inclusion of RAC reduced Boston butt fat content to 15.47% from 16.96% and increased picnic protein content to 19.82% from 19.28%. Furthermore, RAC-fed pigs had greater picnic SSP extractability at 1.5% salt when expressed as percent of total protein. Cottage bacon from RAC-fed pigs was leaner (less fat and increased moisture) and had similar processing characteristics as controls. Inclusion of RAC also increased cottage bacon visual slice lean area. In summary, shoulders from pigs fed RAC might be of benefit to the industry because they provide more pounds of sellable products with decreased percent fat and greater lean area in cured Boston butt. Additionally, there were no detrimental effects on the processing characteristics of the CT butt.

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Tables and Figures

Table 3. Effect of RAC and sex on carcass characteristics of finishing pigs

	RAC, mg/kg		Sex		SEM	*P - Value*		
Item	0	7.4	Barrow	Gilt		RAC	Sex	RAC*Sex
HCW[1], kg	100.31	101.75	103.32	98.73	0.60	0.09	< 0.01	0.99
EPC[2]	50.25	51.50	50.42	51.32	0.65	0.18	0.33	0.75
Loin depth, mm	57.63	59.63	58.4	58.87	0.65	0.03	0.61	0.88
Fat depth, mm	21.93	21.20	23.65	19.48	0.47	0.27	< 0.01	< 0.01

[1]Hot carcass weight

[2]Estimated percent lean

Table 4. Effect of RAC and sex on fresh shoulder cut out values[1]

Item	RAC, mg/kg		Sex		SEM	*P – Value*		
	0	7.4	Barrow	Gilt		RAC	Sex	RAC x Sex
Whole shoulder wt[2], kg	11.87	12.10	12.23	11.75	0.08	0.05	< 0.01	0.49
Trimmed shoulder wt, kg	8.96	9.31	9.24	9.03	0.08	< 0.01	0.03	0.31
% of Hot carcass wt[3]	17.88	18.31	17.90	18.29	0.10	< 0.01	0.01	0.22
Bone-in Boston wt, kg	4.18	4.42	4.32	4.28	0.04	< 0.01	0.38	0.09
% of Hot carcass wt	8.34	8.68	8.36	8.66	0.06	< 0.01	0.00	0.06
Boneless Boston wt, kg	3.84	4.08	3.98	3.94	0.04	< 0.01	0.52	0.08
% of Hot carcass wt	7.65	8.03	7.70	7.98	0.06	< 0.01	< 0.01	0.09
Bone-in picnic wt, kg	4.79	4.90	4.93	4.76	0.04	0.09	0.01	0.91
% of Hot carcass wt	9.54	9.63	9.54	9.63	0.07	0.43	0.34	0.94
Boneless picnic wt, kg	3.82	3.92	3.93	3.81	0.04	0.06	0.01	0.35
% of Hot carcass wt	7.62	7.71	7.62	7.71	0.06	0.28	0.30	0.24
C.T. butt wt, kg	1.95	2.10	2.05	2.00	0.22	< 0.01	0.22	0.99
% of Hot carcass wt	3.89	4.13	3.96	4.05	0.05	< 0.01	0.23	0.93
Shoulder cushion wt, kg	0.74	0.79	0.76	0.76	0.01	0.01	0.99	0.04
% of Hot carcass wt	1.47	1.54	1.47	1.54	0.02	0.04	0.05	0.04

[1]Muscle cut-out specifications from Institutional Meat Purchase Specifications (IMPS), 1997.

[2]Weights of individual shoulder parts were averaged for the two paired shoulders from each of the 120 carcasses.

[3]The summation of paired shoulders and its parts were used to calculate cutting yields as a percent of HCW.

Table 5. Effect of RAC and sex on instrumental color of fresh shoulder muscles

	RAC, mg/kg		**Sex**		**SEM**	***P - Value***		
Item	0	7.4	Barrow	Gilt		RAC	Sex	RAC x Sex
Serratus ventralis								
L*	42.60	42.80	42.68	42.72	0.37	0.71	0.93	0.29
a*	17.10	16.50	17.03	16.57	0.24	0.08	0.18	0.32
b*	5.71	5.75	5.76	5.70	0.23	0.92	0.87	0.07
Triceps brachii								
L*	40.43	40.11	40.54	40.00	0.27	0.16	0.39	0.04
a*	15.39	14.84	15.15	15.08	0.25	0.84	0.12	0.45
b*	2.88	2.44	2.81	2.51	0.18	0.09	0.23	0.22

[1]Objective color scores were averaged across paired shoulders and mean of the two values were reported for a total of 120 observations.
L*, greater value indicates a lighter color; a* greater value indicates a redder color; b* greater value indicates a more yellow color.

Table 6. Interaction LS means between RAC and sex on pH of fresh shoulder muscles[1]

	RAC, mg/kg x Sex					*P* - Value		
Item	0 x Barrow	7.4 x Barrow	0 x Gilt	7.4 x Gilt	**SEM**	RAC	Sex	RAC x Sex
Serratus ventralis	6.28[ab]	6.36[a]	6.23[bc]	6.15[c]	0.04	0.93	< 0.01	0.05
Triceps brachii	6.11[b]	6.25[a]	6.09[b]	6.06[b]	0.03	0.11	< 0.01	0.01

[1]pH values were averaged across paired shoulders and mean of the two values were reported for a total of 120 observations.

[a-c]Different letters indicate $P \leq 0.05$.

Table 7. Effect of RAC and sex on proximate composition and water holding capacity of fresh shoulder[1]

	RAC, mg/kg		**Sex**		**SEM**	***P - Value***		
Item	0	7.4	Barrow	Gilt		RAC	Sex	RAC x Sex
Boston butt								
Moisture, %	64.09	64.49	63.60	64.97	0.42	0.50	0.03	0.16
Fat, %	16.96	15.47	17.24	15.19	0.42	0.01	< 0.01	0.42
Protein, %	18.54	18.73	18.41	18.86	0.13	0.27	0.01	0.02
MPR[2]	3.46	3.45	3.46	3.45	0.02	0.59	0.66	0.21
WHC[3]	21.87	21.54	20.98	22.42	0.59	0.69	0.09	0.64
Picnic								
Moisture, %	65.81	66.94	65.37	67.38	0.34	0.02	<0.01	0.02
Fat, %	14.21	13.89	14.10	13.99	0.43	0.86	0.60	0.29
Protein, %	19.28	19.82	19.16	19.94	0.14	0.01	< 0.01	0.77
MPR	3.39	3.42	3.39	3.42	0.02	0.32	0.33	0.17
WHC	21.77	21.92	21.03	22.66	0.76	0.85	0.04	0.45

[1]Data reported as LS means of 120 shoulders.

[2]Moisture protein ratio = (%Moisture) ⁄ (%Protein.)

[3]Water holding capacity data indicate percent moisture loss after sample centrifugation.

Table 8. Effect of RAC and sex on percent lean of cottage bacon slices from finishing pigs[1]

	RAC, mg/kg		Sex		SEM	*P - Value*		
Item	0	7.4	Barrow	Gilt		RAC	Sex	RAC x Sex
Loin end (Posterior)								
Total area, cm^2	71.10	74.53	71.81	73.82	2.09	0.25	0.50	0.33
Lean area, cm^2	55.31	59.35	57.10	57.55	1.57	0.07	0.84	0.23
Seam fat area, cm^2	15.80	15.17	14.71	16.26	1.22	0.72	0.37	0.61
% seam of total	21.94	19.39	19.90	21.44	1.17	0.12	0.35	0.31
Middle								
Total area, cm^2	94.26	98.14	96.44	95.96	2.09	0.19	0.87	0.62
Lean area, cm^2	65.06	69.04	65.59	68.51	1.57	0.07	0.19	0.17
Seam fat area, cm^2	29.20	29.10	30.85	27.45	1.22	0.95	0.05	0.24
% seam of total	30.84	29.47	31.96	28.35	1.17	0.41	0.03	0.12
Blade end (Anterior)								
Total area, cm^2	75.82	81.56	79.03	78.35	2.09	0.05	0.82	0.21
Lean area, cm^2	57.97	65.17	60.04	63.10	1.57	< 0.01	0.17	0.01
Seam fat area, cm^2	17.85	16.39	18.99	15.25	1.22	0.40	0.03	0.13
% seam of total	23.45	20.05	24.12	19.38	1.17	0.04	< 0.01	0.01
Average								
Total area, cm^2	80.39	84.74	82.42	82.71	1.21	0.01	0.87	0.19
Lean area, cm^2	59.45	64.52	60.91	63.06	0.91	< 0.01	0.10	0.41
Seam fat area, cm^2	20.95	20.22	21.51	19.65	0.70	0.47	0.06	0.23
% seam of total	25.41	22.97	25.33	23.06	0.67	0.01	0.02	0.35

[1]Data reported as LS means of 60 samples.

Table 9. Effect of RAC and Sex on cottage bacon processing characteristics[1]

	RAC, mg/kg		**Sex**		**SEM**	***P - Value***		
Item	0	7.4	Barrow	Gilt		RAC	Sex	RAC x Sex
Green wt, kg	1.98	2.16	2.10	2.04	0.05	0.02	0.46	0.87
Pump wt, kg	2.16	2.36	2.29	2.22	0.06	0.02	0.44	0.92
Cure upatake, %	8.81	9.04	9.00	8.85	0.22	0.48	0.63	0.45
Equilibrium wt, kg	2.15	2.33	2.27	2.21	0.06	0.03	0.47	0.88
Stuffed wt, kg	2.15	2.35	2.28	2.23	0.06	0.02	0.54	0.83
Hot cooked wt, kg	1.95	2.14	2.07	2.01	0.06	0.02	0.46	0.90
Chilled cooked wt, kg	1.91	2.09	2.03	1.97	0.06	0.02	0.44	0.90
Cooked yield, %	95.95	96.44	96.38	96.01	0.27	0.33	0.20	0.88
Evap. Chill loss, %	2.20	2.06	2.06	2.20	0.05	0.06	0.06	0.75
Moisture, %	60.10	61.84	60.27	61.67	0.36	< 0.01	0.01	0.81
Fat, %	18.83	16.90	19.04	16.69	0.44	< 0.01	< 0.01	0.37
Protein, %	19.20	19.44	18.91	19.73	0.25	0.50	0.02	0.39
PFF[2]	23.65	23.38	23.35	23.68	0.26	0.48	0.37	0.60
Cure Color								
L*	53.89	53.71	53.94	53.65	0.32	0.69	0.53	0.08
a*	18.29	18.16	17.79	18.66	0.24	0.70	0.01	0.05
b*	6.29	6.00	6.05	6.24	0.11	0.07	0.24	0.38

[1]Data reported as LS means of 60 samples.

[2]Protein fat free = $\{\%\text{Protein}/(100 - \%\text{Fat})\}$ x 100.

L*, greater value indicates a lighter color; a* greater value indicates a redder color; b* greater value indicates a more yellow color.

Table 10. Effect of RAC and sex on sensory evaluation of cottage bacon[1]

	RAC, mg/kg		**Sex**		**SEM**	***P - Value***		
Item	0	7.4	Barrow	Gilt		RAC	Sex	RAC x Sex
Texture	8.76	8.55	8.78	8.52	0.17	0.36	0.27	0.93
Juiciness	8.17	7.77	8.11	7.84	0.17	0.09	0.25	0.81
Saltiness	7.66	7.24	7.42	7.48	0.16	0.07	0.79	0.82
Off-flavor	0.37	0.17	0.12	0.42	0.10	0.18	0.04	0.24

[1]Sensory attributes were evaluated using a 0 to 15 cm hedonic scale. Where 0 indicates mealy, extremely dry, no salt and none intense off flavor; 15 indicates crumbly, extremely juicy, salty and extremely intense off flavor.

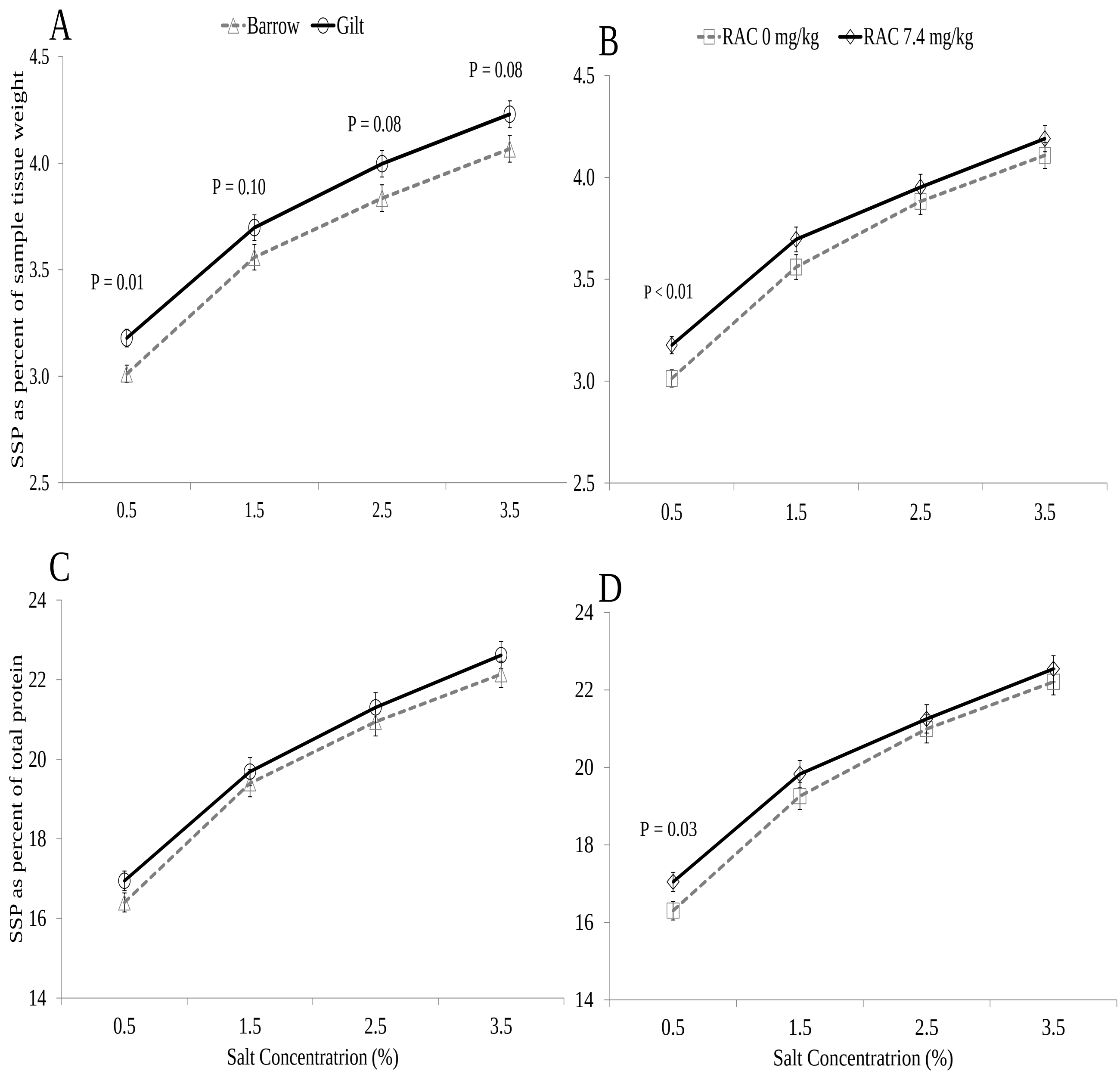

Figure 1. Salt-soluble proteins (SSP) from the Boston butt expressed as percentage of tissue weight over an increasing concentration of sodium chloride in the extraction buffer between barrows and gilts (A) and RAC and controls (B); or expressed as percentage of total protein over an increasing concentration of sodium chloride in the extraction buffer between barrows and gilts (C) and RAC and controls (D). Only $P \leq 0.10$ were presented in the graph.

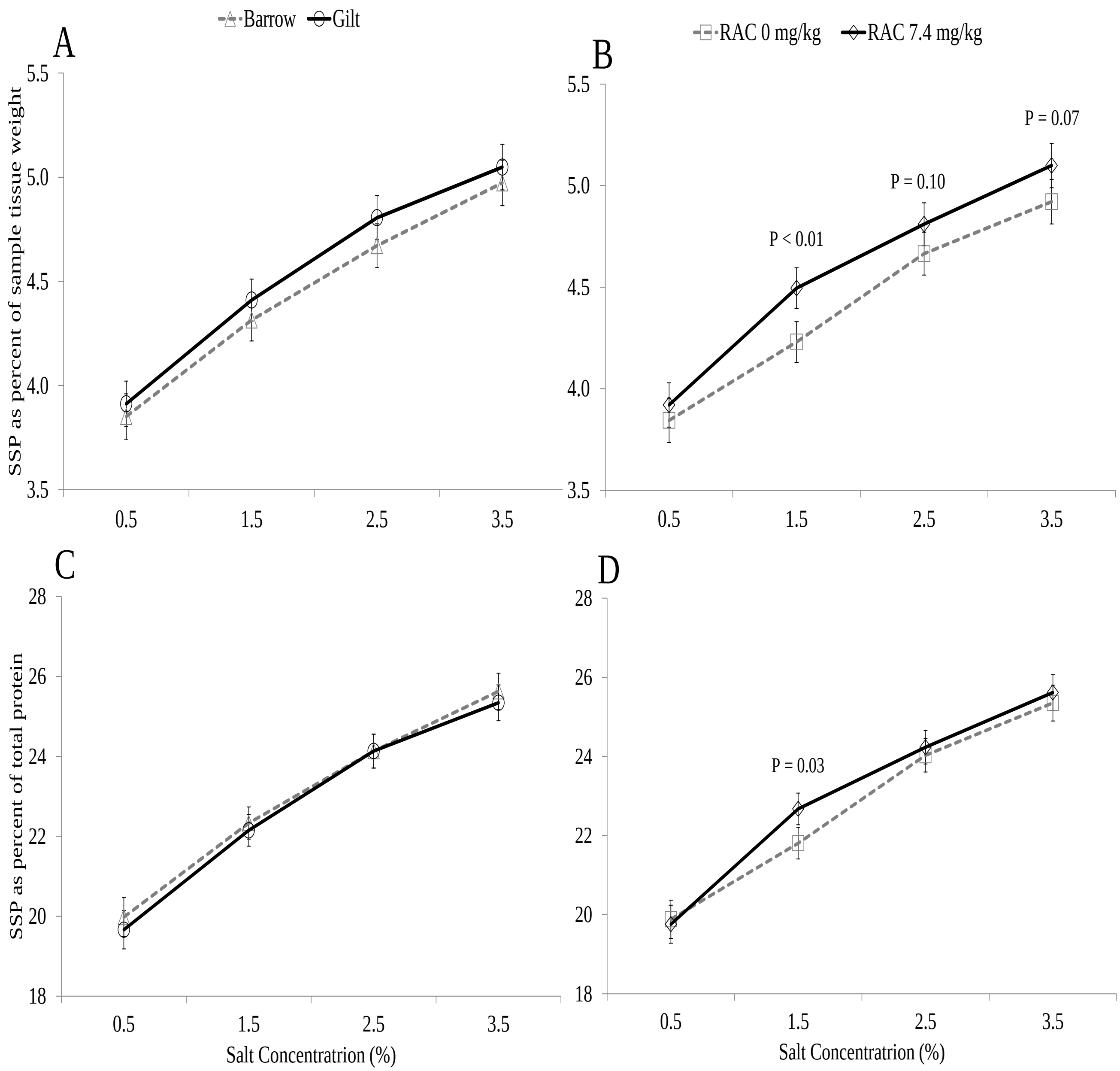

Figure 2. Salt-soluble proteins (SSP) from the picnic expressed as percentage of tissue weight over an increasing concentration of sodium chloride in the extraction buffer between barrows and gilts (A) and RAC and controls (B); or expressed as percentage of total protein over an increasing concentration of sodium chloride in the extraction buffer between barrows and gilts (C) and RAC and controls (D). Only $P \leq 0.10$ were presented in the graph.